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INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 6 : E21B 43/34, 43/40, B01D 17/02, 17/04, 19/00	A2	(11) International Publication Number: WO 98/54441 (43) International Publication Date: 3 December 1998 (03.12.98)

(21) International Application Number: PCT/GB98/01556

(22) International Filing Date: 28 May 1998 (28.05.98)

(30) Priority Data:
9711130.6 29 May 1997 (29.05.97) GB

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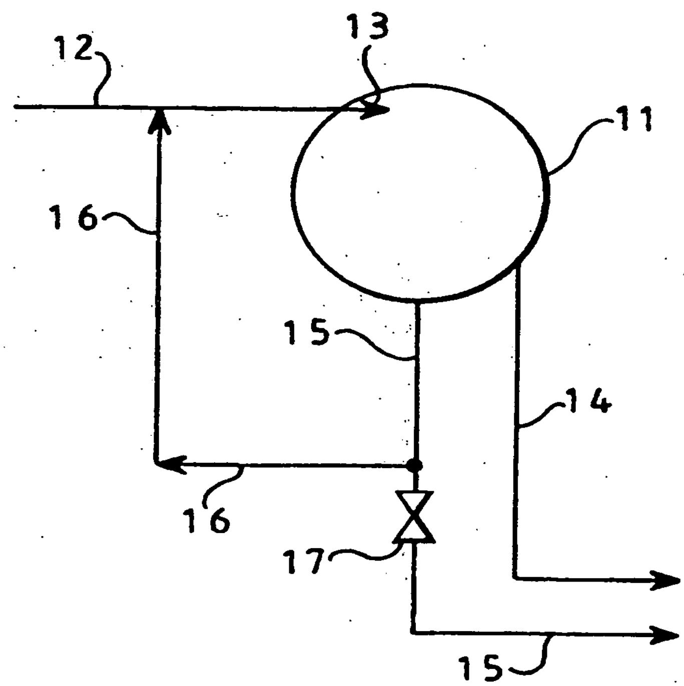
(81) Designated States: AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CU, CZ, DE, DK, EE, ES, FI, GB, GE, GH, GM, GW, HU, ID, IL, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, UA, UG, US, UZ, VN, YU, ZW, ARIPO patent (GH, GM, KE, LS, MW, SD, SZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, ML, MR, NE, SN, TD, TG).

Published
Without international search report and to be republished upon receipt of that report.

(54) Title: METHOD AND APPARATUS FOR MULTI–PHASE SEPARATION

(57) Abstract

A process and apparatus for separating fluids of different density, primarily gas, oil and water from an oil well production flow (12), including a rotary separation turbine (11) separating at least the gas phase, but preferably also the liquid phases, and preferably returning water (16) to the separation step to increase the water cut of the mixture being separated.



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METHOD AND APPARATUS FOR MULTI-PHASE SEPARATION

Background of the Invention

This invention relates to a process and apparatus for separating gas and liquid from a pressurised flow from an oil well, utilising a rotary separation turbine.

Rotary separation turbines are known, US Patent No 4087261 and 5525034 being illustrative of known arrangements. As will be well understood by those familiar with rotary separation turbines, the pressurised liquid flow containing dissolved gas is directed into the turbine assembly through a specially designed nozzle where the expansion energy derived from the gas "flashing" out of solution is transferred to kinetic energy in the jet issuing from the nozzle and impinging upon the turbine rotor. The interaction of the accelerated jet with the turbine rotor drives the rotor and a liquid layer which forms on and rotates with the rotor undergoes centrifugal separation as a result of the high rotational speed, to separate any remaining gas from the liquid. Where, as in US Patent No 4087261, there are solids and/or mixtures of immiscible liquids (oil and water) of different density, these will be separated by centrifugal stratification of the liquid into various coaxial layers on the turbine rotor. Energy can be recovered from the system by way of a rotating output shaft driven by the turbine rotor, and/or in the form of liquid pressure by means of one or more diffuser scoops intercepting the or each liquid layer rotating with the turbine rotor.

Summary of the Invention

In accordance with the first aspect of the present invention there is provided a process for separating fluids of different density from a

pressurized fluid mixture, comprising supplying the flow to a rotary separation turbine and utilizing energy derived from the flow by the rotary separation turbine to pressurize a supply of one of said fluids for supply to the separation process to increase the proportion of that fluid in the process.

In accordance with another aspect of the present invention there is provided a process for separating gas, water and oil from a pressurized flow from an oil well comprising supplying the flow to a rotary separation turbine and utilizing energy derived from the flow by the rotary separation turbine to pressurize water to supply to the separation process to increase the water proportion in the process.

Preferably the water is derived from the inlet flow, is collected downstream of the input nozzle of the rotary separation turbine, and is recycled to the inlet flow upstream of the nozzle of the rotary turbine separator.

Alternatively the water is derived from the inlet flow, is collected downstream of the inlet nozzle of the rotary separation turbine, and is recycled to the rotary turbine separator downstream of its inlet nozzle.

Preferably the water is collected from the rotor of the rotary separation turbine by a diffuser scoop in which sufficient pressure is generated to recycle the water.

Alternatively the water is derived from a low pressure source separate from the inlet flow and is pressurized by energy derived from the inlet flow by the rotary separation turbine for supply to the separation process.

Preferably the water is supplied to the separation process upstream of the nozzle of the rotary separation turbine.

Alternatively the water is supplied to the separation process immediately downstream of the nozzle of the rotary separation turbine.

Conveniently the water is derived from the inlet flow by separation within the rotary separation turbine.

Alternatively the water is derived from the inlet flow by a separation stage subsequent to the separation in the rotary separation turbine.

Desirably the separation stage subsequent to the rotary separation turbine is a further rotary separation turbine.

Alternatively said separation stage subsequent to the rotary separation turbine includes a hydrocyclone.

In accordance with a further aspect of the present invention there is provided a separation process including the steps of treating the flow from an oil well in a first, high pressure, rotary separation turbine, to remove a first proportion of the dissolved gas therefrom, and supplying some of the products of the first stage separation to a second stage separation operating at a lower pressure to remove further dissolved gas from the flow.

Preferably some of the product of the second stage separation turbine is passed to a third stage separation operating at a still lower pressure to retrieve the remaining dissolved gas from the inlet flow.

In accordance with a further aspect of the present invention there is provided a process for separating gas and liquid from a pressurized flow from an oil well comprising de-gassing, or substantially de-gassing the flow in a rotary separation turbine, and then subjecting the de-gassed flow to oil and water separation in a liquid/liquid hydrocyclone.

The invention further resides in apparatus for use in separation of gas, oil and water for a pressurized flow from an oil well, including a rotary separation turbine and means utilizing energy derived from the flow by the RST for pressurizing water to supply to the separation process.

In accordance with a further aspect of the invention there is provided a process for separating phases of a multi-phase flow comprising feeding the flow to a rotary separation turbine the rotor of which is rotated at sufficient speed to achieve phase separation of the flow and utilizing such rotation of the rotor and at least one of the separation phases to generate sufficient pressure in an output line of said phase to permit recycling of said phase at least in part into either the inlet flow of the RST or into the casing of the RST.

Preferably the turbine rotor is driven, at least in part, by an energy source external to said multi-phase flow.

In accordance with a still further aspect of the present invention there is provided a process for separating oil and water from a combined flow including treating the combined flow in a rotary separation turbine to separate the oil and water and adding water either to the flow entering the rotary separation turbine or to the flow in the rotary separation turbine.

Conveniently said water is added by means of an external pump.

Alternatively said water is recycled from the separated water leaving the rotary separator turbine.

Desirably said water is recycled by pressure generated by rotation of the rotor of the rotary separation turbine.

Conveniently the rotary separation turbine is driven, at least in part, by an energy source external to said combined oil and water flow.

Brief Descrition of the Drawings

In the accompanying drawings:-

Figure 1 is a diagrammatic representation of a multi-phase separation apparatus in accordance with a first example of the present invention;

Figures 2 and 3 are views similar to Figure 1 illustrating modifications;

Figure 4 is a view similar to Figure 1 of apparatus in accordance with a second example of the present invention;

Figure 5 is a diagrammatic representation of a multi-stage multi-phase separation apparatus in accordance with a third example of the present invention; and

Figure 6 is a view similar to Figure 5 of a modification thereof.

Detailed Descrition of the Preferred Embodiments

Referring first to Figure 1 of the accompanying drawings, the multi-phase separation apparatus is based upon a rotary separation turbine (hereinafter referred to as an RST) which may, conveniently, be in the form disclosed in US Patent No 4087261. The exact structure of the RST 11 is not of importance to the present invention, it being understood that the RST rotor is driven by, and separates the phases of, a high pressure stream derived from an oil well. The stream contains water, oil, and dissolved gases under substantial pressure (for example 150 bar) and is fed to the inlet nozzle of the RST without any substantial pressure reduction. The design of the inlet nozzle of the RST is, as will be understood by experts in the turbine separation field, such that it promotes a rapid evolution, and expansion of the gas from solution and uses the energy of expansion to accelerate the homogenous, and focused jet of gas and liquid issuing from the nozzle. The nozzle directs the focused jet substantially tangentially onto an internal cylindrical surface of the turbine rotor causing the rotor to spin about the axis of the cylindrical surface, it being understood that the surface of the rotor may be a right circular cylinder or an axially tapering cylinder or variants thereof. The liquid impinging on the rotor forms a layer rotating with the rotor, and thus subjected to centrifugal forces in accordance with the speed of rotation of the rotor. The rotation generates centrifugal separation within the liquid layer so that further gas is evolved into the casing of the RST and the liquid layer is stratified to form coaxial layers of oil and water, the oil being less dense than the water, and thus forming radially inwardly of the water layer.

Stationary diffuser scoops extend into the oil and water layers respectively to provide a discharge route for the oil and water, the

pressure generated in the scoops and associated piping being determined by the flow resistance within that piping, and the speed of rotation of the oil and water layers relative to the scoops.

In Figure 1 it can be seen that the wellhead flow is directed along line 12 to the inlet nozzle 13 of the rotary separation turbine 11 where it is jetted onto the turbine rotor. Separation of the gas, oil and water occurs within the RST 11 the gas exiting from the casing of the RST at a predetermined pressure governed by variable restrictors in the outlet path of the gas. The gas is collected for further processing, although the pressure which is allowed to develop in the casing of the RST 11 is preferably controlled to be such that as little as possible further pressurization of the gas is necessary in the passage of the gas to its further processing stages. This pressure will of course be substantially less than wellhead pressure persisting upstream of the nozzle 13. The oil layer forming within the turbine rotor is discharged by way of the oil scoop and an outlet line 14 for storage, or further processing, the oil pressure in the line 14 being determined by the speed of rotation of the turbine rotor (and therefore the oil layer) and controllable restrictors in the line 14. The purity of the oil layer may be such that further separation of the oil phase is not necessary, and the oil can pass to storage, or by way of pipe line to the refinery. However, it is to be recognised that if necessary the oil discharged by way of the line 14 may be subjected to a further processing stage, for example, to reduce even further the proportion of entrained water droplets.

Similarly the water layer forming within the turbine rotor is discharged through the water scoop into an outlet line 15. As with the discharged oil, the discharged water may be sufficiently pure to be discharged back

to the environment, but if not then it may be subjected to further processing to reduce the proportion of entrained oil droplets.

A known problem with existing separation systems, particularly gravity separation systems, is the formation of a stable oil/water emulsion layer between the separated oil and water layers. It is believed that the formation of such an emulsion layer can be inhibited by increasing the proportion of water to oil in the inlet flow to the separator (usually known as increased water cut). Irrespective of inhibiting the formation of an emulsion layer it is recognised that increasing the water cut improves the efficiency of separation of oil and water as it is easier for oil droplets to migrate through a water phase than for water droplets to migrate through an oil phase. However in gravity separation systems increasing the water cut leads to larger and more expensive separator vessels and to the need to supply energy to pump water into the vessel at the pressure existing therein.

In Figure 1 it can be seen that a line 16 interconnects the line 15 and the line 12 so that water can be recycled from the line 15 into the inlet flow upstream of the nozzle 13. Thus the facility exists for augmenting the water cut of the inlet stream in those situations where the water cut is below a predetermined level at which oil/water separation is prejudiced and/or it is expected that emulsion formation is likely.

It will be recognised that in order that there can be a flow along the line 16 from the line 15 to the line 12 then the pressure in the line 15 must exceed that in the line 12. Such pressure can be generated by the diffuser scoop, collecting the water from the water layer and it will be noted that there is a control valve 17 in the line 15 downstream of the

point of interconnection of the lines 15 and 16. Although not shown in the drawings it is to be recognised that a non-return valve will be incorporated in the line 16 to prevent any possibility of flow from the line 12 to the line 15.

Control over the operation of the valve 17, to control recycling of water from the line 15 by way of the line 16 to the line 12 can take a number of forms. Figure 2 for example shows a fraction meter 18 positioned either upstream, or alternatively downstream, of the point of interconnection of the lines 16 and 12. The fraction meter 18 monitors, in real time, the relative proportions of oil and water in the flow passing through it, and thus can provide a control signal controlling operation of the valve 17 to increase or decrease the amount of water being recycled to ensure that the water cut of the flow entering via the nozzle 13 is above the predetermined level.

Figure 3 illustrates an alternative arrangement in which the result of the separation process is used to control the amount of water recycled. Thus the line 15 and/or the line 14 are provided with fraction meters which monitor the water/oil flows and provide a control signal for the valve 17 to vary the amount of recycled water accordingly.

In a further alternative the inlet flow in the line 12 is periodically sampled to determine the oil/water ratio and to establish the lowest water cut which can be tolerated. A simple flow meter continuously measures the rate of flow in the line 12, and thus the flow entering the RST 11. The periodically sampled oil/water ratio, together with the flow in the line 12 is then used to control the operation of the valve 17 to ensure that sufficient water is recycled to ensure that the flow entering

the RST has a water cut which always exceeds the predetermined lowest value. Where the lowest acceptable water cut can be predetermined and is expected to remain valid for a significant period in the operation of the well, then a simple system of recycling water can be achieved by providing the RST with a further diffuser scoop in the water layer dedicated solely to recycling. The scoop is designed to extract sufficient water to recycle to ensure that the water cut is significantly in excess of the predetermined lowest acceptable value. Thus monitoring is unnecessary, the excess over the lowest acceptable value will be sufficient to damp out the effect of minor operating variations in the oil/water proportions of wellhead flow, and since the scoop extracts in accordance with rotor speed then the system will tend to be self regulating in relation to inlet flow rate variations. Increasing the water cut to give a large margin over the lowest acceptable value in relation to separation efficiency and/or emulsion formation also minimises the risk of oil from the oil layer entering the or each water scoop should there be an oil 'slug' or the like in the inlet flow.

If there is entrained sand, or other solid particles in the inlet flow, then these may be dealt with upstream of the nozzle 13, by for example a filter or a cyclonic desander, so that no such particles enter the RST. However, it is found that RSTs are in general tolerant to entrained solid particles in the inlet flow by virtue, it is believed, of the jet from the nozzle 13 impinging upon a liquid layer on the turbine rotor. Thus the risk of erosion of the turbine rotor by the solid particles is minimised since their energy is absorbed in the liquid layer. However, during separation the solid particles, being more dense than the water phase, migrate to form a layer radially outwardly of the water layer and if desired these can be removed by a further scoop as described in US

Patent No 4087261. An alternative however is to provide passages in the wall of the turbine rotor through which the solid particles are flushed by water from the water layer. The passages can be shaped at the exterior of the turbine rotor to define reaction jets whereby the escape of water and solid particles augments the rotation energy of the turbine rotor. The solid particles and the flushing water are then collected in an involute of the stationary casing of the RST for discharge in any convenient manner.

It will be recognised that the removal of solid particles either by flushing, or by a scoop removes water from the water layer. Where the water cut is already low, then there may be a risk that the water cut falls too low both in terms of the risk of formation of emulsions, and in terms of the risk of reducing separation efficiency. To accommodate such a situation make-up water from an alternative source can be added to the flow impinging on the turbine rotor. It will be recognised however that if make-up water is to be added to the inlet flow upstream of the nozzle, then it must be pressurized to a pressure in excess of the pressure in the line 12. Thus it is proposed to add make-up water through a separate nozzle into the confines of the turbine rotor where of course the pressure is much less than the pressure in the line 12, being the pressure at which the evolved gas is being taken from the system. Thus the energy input necessary to supply make-up water is less than that which would be necessary to supply the water into the line 12.

It will be understood that the RST transfers energy from the wellhead flow either by pressurizing the gas, oil and water outlet flows, and/or by a power take-off from the rotor of the RST. The rotor can drive a shaft driving a compressor or pump, for example for supplying make-up water

to the RST casing, or alternatively can drive an electric motor/generator which can generate electrical power or alternatively can be used to consume electrical power from another source, to run the RST up to speed at the commencement of a separation operation.

Figure 4 illustrates a further example of the present invention.

The rotary separation turbine 21 is similar to the turbine 11 described in general above, but is designed to achieve gas/liquid separation rather than gas/oil/water separation. Thus the wellhead flow passes along the line 12 to the nozzle 13 of the RST 21 and the gas evolved between the nozzle and the turbine rotor, and during separation on the turbine rotor, is extracted from the RST casing as described above. The liquid phase is not treated as separate oil and water layers and is collected by a scoop which discharges through an output line 22. The outlet line 22 thus receives a de-gassed oil and water mixture which is then supplied to the inlet of a liquid/liquid hydrocyclone 23 of known form. The hydrocyclone 23 separates the oil and water to produce an oil overflow by way of an output line 14 and a water underflow by way of an outlet line 15. A control valve 17 is provided in the outlet line 15 and a water recirculation line 16 interconnects the line 15 upstream of the valve 17 with the line 12 upstream of the nozzle 13.

The pressure which can be generated in the line 22 is more than adequate to supply the hydrocyclone 23 so as to achieve efficient oil and water separation in the hydrocyclone 23. The pressure in the line 22 can be such that the water pressure in the line 15 can still exceed the pressure in the line 12, and thus recirculation of water from the outlet line 15 to the inlet flow in the line 12 can take place exactly as

described above, and control over the valve 17 can be achieved by the same types of monitoring techniques as are described above in relation to the three-phase RST 11.

Forms of centrifugal separator other than a hydrocyclone could be used, for example a compact centrifuge driven by power derived from the RST rotor shaft could be utilized.

It will be recognised that the use of a two-phase RST 21 to de-gas the wellhead flow and then to provide a pressurized supply of de-gassed oil/water mixture to a centrifugal separator may, in many applications, be advantageous over the additional complexity of three-phase separation in a rotary separation turbine and thus is a concept which is novel and inventive in its own right irrespective of whether or not its operation is augmented by recycling of water through a line 12.

It will be recognised that the quantity of gas which is evolved from the wellhead flow is determined in part by the pressure drop which the flow experiences. Figure 5 illustrates a separation string utilizing a number of turbine separation stages. In its broadest concept the string can utilize either two phase RSTs as mentioned above in relation to Figure 4, and as shown, for example, in US Patent No 5525034 or three-phase RSTs in which the liquid phase is separated into oil and water layers, or a mixture of three and two phase RSTs, or a mixture of RSTs and other forms of separator. In Figure 5 three-phase RSTs are illustrated as will become clear later.

The wellhead flow in Figure 5 is directed along a line 12 to the nozzle 13 of a first three-phase RST 11. Gas is evolved within the casing of the

turbine 11 in the usual manner, and provides the energy to accelerate the liquid jet to drive the turbine rotor where further gas separation occurs. The gas pressure within the casing of the separator 11 is controlled to be, for example 70 bar, and thus gas extracted from the casing of the first stage separator 11 needs little or no re-pressurization before being transported for storage or further processing. Water from the water layer forming on the turbine rotor is discharged by way of a diffuser scoop into a water outlet line 15, and the scoop associated with the oil layer forming on the turbine rotor discharges the oil layer through an oil outlet line 14. Incomplete oil and water separation has taken place, and so the oil outlet flow contains water. More importantly however the oil output flow still contains dissolved gas as not all of the dissolved gas in the inlet flow from the line 12 was evolved within the casing of the turbine 11 owing to the relatively high pressure (70 bar) conditions in the casing.

A second stage RST 11a has its input line 12a connected to the output line 14 of the first stage RST 11. The pressure conditions in the casing of the RST 11a are controlled to a maximum of, for example, 30 bar and so the inlet flow from the line 12a evolves further dissolved gas as it passes through the inlet nozzle of the RST 11a. Again water is discharged through a line 15a and an oil flow is discharged through a line 14a. The gas evolved within the RST 11a is at 30 bar, and thus partial re-pressurization only is necessary in order to transfer the gas for storage or further processing. The oily flow from the outlet 14a still contains dissolved gas, and thus still contains sufficient energy to drive a third stage RST. Thus the line 14a is connected to the inlet line 12b of a third stage RST 11b, the casing of which is controlled to a pressure of, for example, 2 bar. Gas is therefore evolved as the flow from the line 14a

passes through the inlet nozzle of the RST 11b thus driving the turbine rotor and achieving final separation such that the remaining water is discharged through the output line 15b of the separator 11b and oil is discharged through the output line 14b of the separator 11b.

The evolved gas in the casing of the separator 11b needs significant re-pressurization for storage or further processing, but it will be recognised that of the total gas content of the wellhead flow only a small proportion needs added energy for re-pressurization.

Where there is a string of rotary turbine separators as illustrated in Figure 5 then recycling of water can be achieved very simply. It can be arranged, by throttling the output flow in the line 15b of the final stage that the pressure in the line 15b exceeds the casing pressure of the second stage RST 11a. Thus a line 16b can be used to recycle water from the output line 15b of the final stage into the casing of the second stage RST 11a. Similarly, water can be recycled from the output line 15a of the second stage RST 11a through a line 16a to the casing of the first stage RST 11.

It will be recognised that the supply of recycled water into the casing of the RST is particularly useful where the water is being used to make-up the water layer forming on the rotor of that RST, replacing, for example, water lost through flushing of solid particles through reaction jets. Thus in effect make-up water can be supplied from a low pressure source to the highest pressure, first stage RST 11 using only the energy released by the evolution and expansion of gas from the wellhead flow. Figure 5 illustrates a line 25 supplying make-up water from an external low pressure source to the casing of the final stage RST 11b. It will be

recalled that the pressure in the casing of the RST 11b is nominally 2 bar and thus make-up water can be supplied through the line 25 from a low pressure source without re-pressurization by pumping or the like. Some of the water added from the line 25 to the final stage is of course recycled through the line 16b to the intermediate stage, and thus by way of the line 16a to the first (high pressure) stage.

Where recycled water is used primarily to enhance the water cut to minimise the risk of emulsion formation it is believed that it is better to augment the water cut upstream of the separator nozzle. Thus it is necessary to supply the recycled water at a higher pressure than would be the case if the water was being used as, for example, make-up water supplied directly into the casing of the RST through its own inlet nozzle. It will be recognised that if desired the output pressure in the lines 15a, 15b can be arranged to be high enough for the recycle lines 16b, 16a to supply recycled water to the input lines 12, 12a rather than directly into the casings of the RSTs 11 and 11a. However, Figure 6 illustrates an alternative arrangement.

In a modification of the arrangement illustrated in Figure 5 the first stage three phase RST 11 is capable of completely separating the oil and water phases of the input flow from the wellhead. Thus no water passes to the second and third stage RSTs 11a, 11b and these RSTs can therefore be two phase RSTs which simply de-gas the oil phase derived from the RST 11. Moreover in place of the or each two phase RST it would be possible to use, for example, a gas/liquid hydrocyclone for de-gassing the oil phase. Recycling of water from the RST 11 within the RST or back upstream of its inlet nozzle 13 can of course still be used if necessary. It will be recognised that de-gassing RSTs will recover energy which can be

used directly by way of an oil scoop to pressurize the oil outlet or by way of shaft take-off to pressurize the gas evolved, or to utilize the recovered energy to drive a generator providing electrical power.

In Figure 6 the RSTs 11, 11a, 11b are shown as having an additional output line 26, 26a and 26b respectively. These lines are supplied from respective additional diffuser scoops which cooperate with the water layer of their respective turbine rotor. Thus the pressure in the line 26 is arranged to exceed the pressure in the line 12 so that a connection of the line 26 to the line 12 upstream of the nozzle 13 permits recirculation of water back into the inlet flow of the RST 11. Control valves and non-return valves will be associated with the line 26 as described above to ensure that there can be no return flow from the line 12 through the line 26, and to ensure that appropriate amounts of water are recycled in accordance with monitored parameters of the system. The output line 26a of the second stage RST 11a is shown, in Figure 6, to be connected to the line 26 of the first stage RST 11. Similarly the output line 26b of the third stage RST 11b is shown connected to the input line 12a of the second stage RST 11a. It will be recognised however that if desired in addition the line 26a can also be connected directly back to its input line 12a and the line 26b can also be connected directly back to its input line 12b (as shown in broken lines in Figure 6). In such an arrangement there is the facility for controlled recirculation of water from the output 26 to the input 12 of each of the three stages separately from one another. However, in addition the third stage RST 11b is provided with a low pressure make-up water supply 25b and by virtue of the connection of the line 26b also to the input line 12a of the second stage RST then make-up water can be supplied to the RST 11a upstream of its nozzle. Similarly by virtue of the connection of the output line 26a to

the line 26 (and through the line 26 to the input line 12) of the first stage RST 11, then make-up water derived from the line 25 can be supplied from the RST 11a to the input flow of the RST 11 upstream of its nozzle. If desired the make-up or recycled water can be supplied to the respective RST casing rather than its input line 12.

In the multistage arrangements of Figures 5 and 6 it would be possible in some cases to use only two stages whereas in other cases more than three stages would be advantageous.

It will be recognised that in all of the embodiments described above the energy of the dissolved gas contained in the input flow from the wellhead of the oil well is used to drive the separation system, and to recycle water derived from the input flow, or from a make-up source. Thus the systems are extremely energy efficient since they do not require an external energy input (except perhaps during start-up when it is desirable to run the RSTs up to speed before separation is allowed to commence), and they can provide the products of separation at pressures suitable for further processing. Furthermore, in most cases there is remaining surplus energy which can be transferred by output shafts connected to the turbine rotors, either to provide pumping energy, or electrical energy by way of a generator or motor/generator driven by the shaft. However it is to be understood that some wellhead flows may contain insufficient gas to provide the necessary energy to run the or each RST rotor up to the required speed for efficient separation and/or pressure take-off by means of a scoop for water recycle. In such situations the arrangements described above can have their rotors driven wholly or in part by externally derived energy to achieve the desired rotor speed for separation and/or recycle. Similarly if appropriate the

pressure to recycle water or to supply make-up water can be supplied by way of an externally driven pump.

Furthermore, while the invention is principally concerned with the separation of oil water and gas mixtures from oil well production flows, it is to be recognised that it can find use in other environments where mixtures of fluids of different densities are to be separated.

CLAIMS

1. A process for separating fluids of different density from a pressurized fluid mixture, comprising supplying the flow to a rotary separation turbine and utilizing energy derived from the flow by the rotary separation turbine to pressurize a supply of one of said fluids for supply to the separation process to increase the proportion of that fluid in the process.

2. A process for separating gas, water and oil from a pressurized flow from an oil well, comprising supplying the flow to a rotary separation turbine and utilizing energy derived from the flow by the rotary separation turbine to pressurize water to supply to the separation process to increase the water proportion in the process.

3. A process as claimed in Claim 2, wherein the water is derived from the inlet flow, is collected downstream of the input nozzle of the rotary turbine separator, and is recycled to the inlet flow upstream of the nozzle of the rotary turbine separator.

4. A process as claimed in Claim 2, wherein the water is derived from the inlet flow, is collected downstream of the inlet nozzle of the rotary turbine separator, and is recycled to the rotary turbine separator downstream of its inlet nozzle.

5. A process as claimed in any one of Claims 2 to 4, wherein the water is collected from the rotor to the rotary separation turbine by a diffuser scoop in which sufficient pressure is generated to recycle the water.

6. A process as claimed in Claim 2, wherein the water is derived from a low pressure source separate from the inlet flow and is pressurized by energy derived from the inlet flow by the rotary separation turbine for supply to the separation process.

7. A process as claimed in Claim 6, wherein the water is supplied to the separation process upstream of the nozzle of the rotary separation turbine.

8. A process as claimed in Claim 6, wherein the water is supplied to the separation process immediately downstream of the nozzle of the rotary separation turbine.

9. A process as claimed in any one of Claims 2 to 4, wherein the water is derived from the inlet flow by separation within the rotary separation turbine.

10. A process as claimed in any one of Claims 2 to 4, wherein the water is derived from the inlet flow by a separation stage subsequent to the separation in the rotary separation turbine.

11. A process as claimed in Claim 10, wherein the separation stage subsequent to the rotary separation turbine is a further rotary separation turbine.

12. A process as claimed in Claim 10, wherein said separation stage subsequent to the rotary separation turbine includes a hydrocyclone.

13. A process for separation of gas and liquid from a pressurized flow from an oil well including the steps of treating the inlet flow from an oil well in a first, high pressure, rotary separation turbine, to remove a first proportion of the dissolved gas therefrom, and supplying some of the products of the first stage separation to a second stage separation operating at a lower pressure to remove further dissolved gas from the flow.

14. A process as claimed in Claim 13, wherein some of the product of the second stage separation is passed to a third stage separation operating at a still lower pressure to retrieve the remaining dissolved gas from the inlet flow.

15. A process for separating gas and liquid from a pressurized flow from an oil well comprising de-gassing, or substantially de-gassing the flow in a rotary separation turbine, and then subjecting the de-gassed flow to oil and water separation in a liquid/liquid hydrocyclone.

16. A process as claimed in Claim 1 incorporating the process of Claim 13 or Claim 14.

17. Apparatus for use in separation of gas, oil and water from a pressurized flow from an oil well, including a rotary separation turbine and means utilizing energy derived from the flow by the RST for pressurizing water to supply to the separation process.

18. A process for separating phases of a multi-phase flow comprising feeding the flow to a rotary separation turbine the rotor of which is rotated at sufficient speed to achieve phase separation of the

flow and utilizing such rotation of the rotor and at least one of the separation phases to generate sufficient pressure in an output line of said phase to permit recycling of said phase at least in part into either the inlet flow of the RST or into the casing of the RST.

19. A process as claimed in Claim 18, wherein said turbine rotor is driven, at least in part, by an energy source external to said multi-phase flow.

20. A process for separating oil and water from a combined flow including treating the combined flow in a rotary separation turbine to separate the oil and water and adding water either to the flow entering the rotary separation turbine or to the flow in the rotary separation turbine.

21. A process as claimed in Claim 20, wherein said water is added by means of an external pump.

22. A process as claimed in Claim 20 or Claim 21, wherein said water is recycled from the separated water leaving the rotary separator turbine.

23. A process as claimed in Claim 22, wherein the water is recycled by pressure generated by rotation of the rotor of the rotary separation turbine.

24. A process as claimed in any one of Claims 20 to 23, wherein the rotary separation turbine is driven, at least in part, by an energy source external to said combined oil and water flow.

25. Apparatus for use in separation of gas, oil and water from an oil well production flow, comprising a rotary separation turbine for removing the gas from the mixture and a centrifugal separator system including at least one hydrocyclone receiving and separating into oil and water phases, the oil and water mixture from the rotary separation turbine.

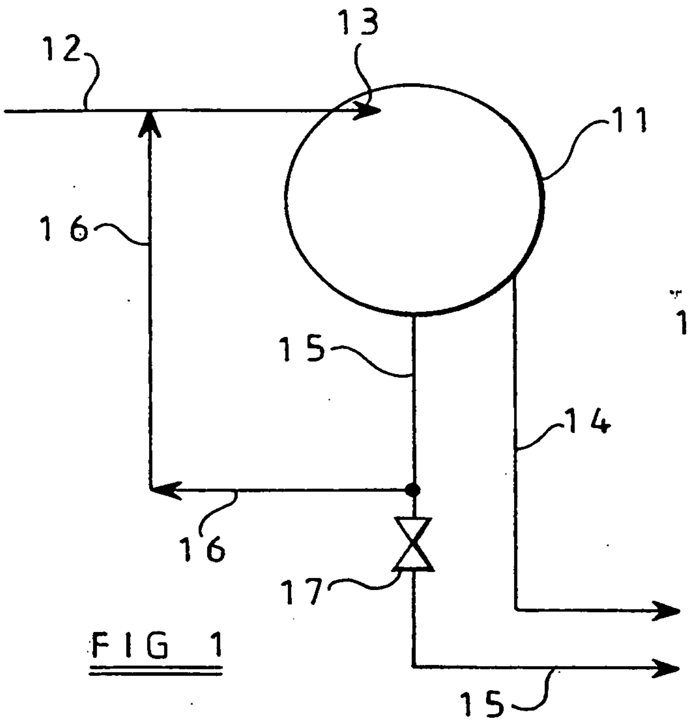

FIG 1

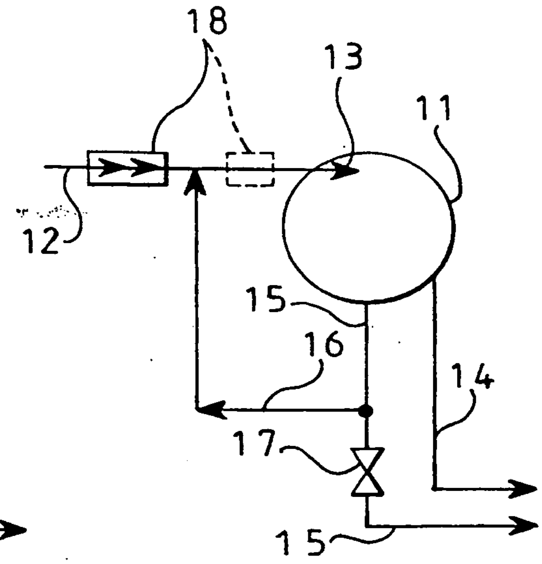

FIG 2

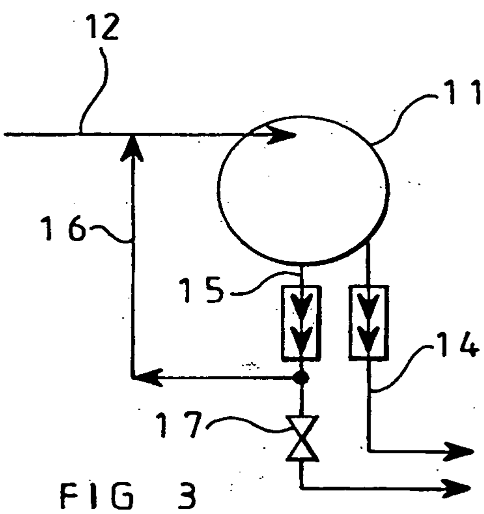

FIG 3

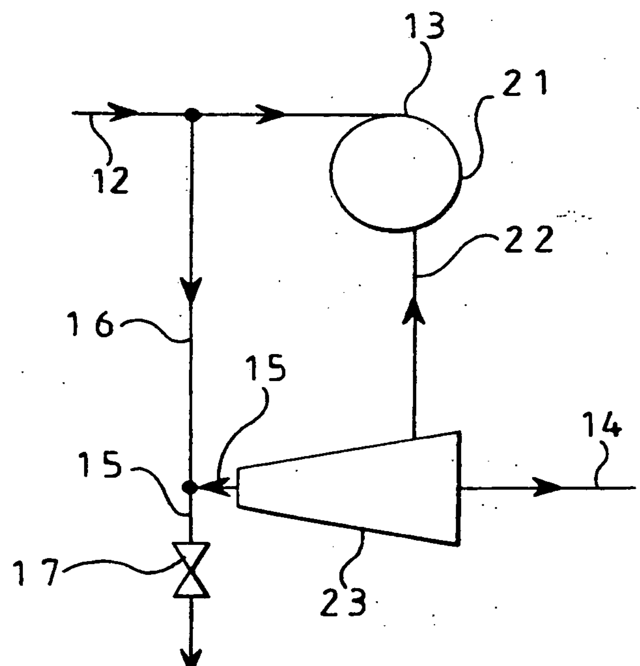

FIG 4

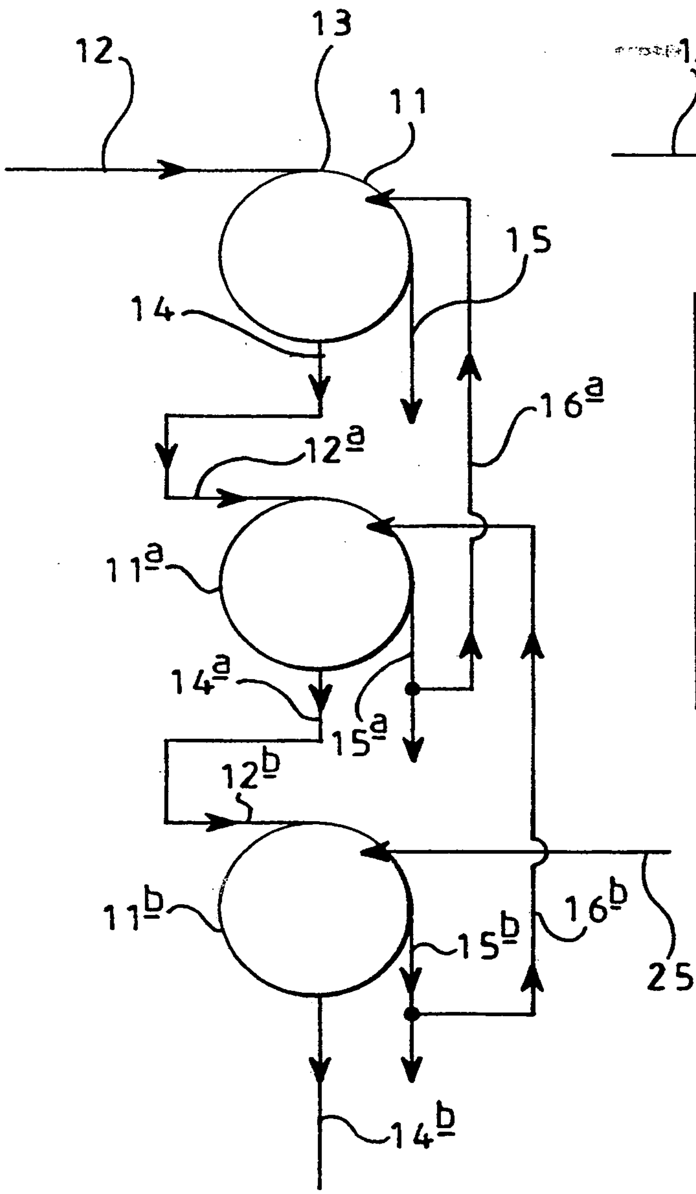
12
13
11
15
14
16a
12a
11a
14a
15a
12b
11b
15b
16b
25
14b

FIG 5

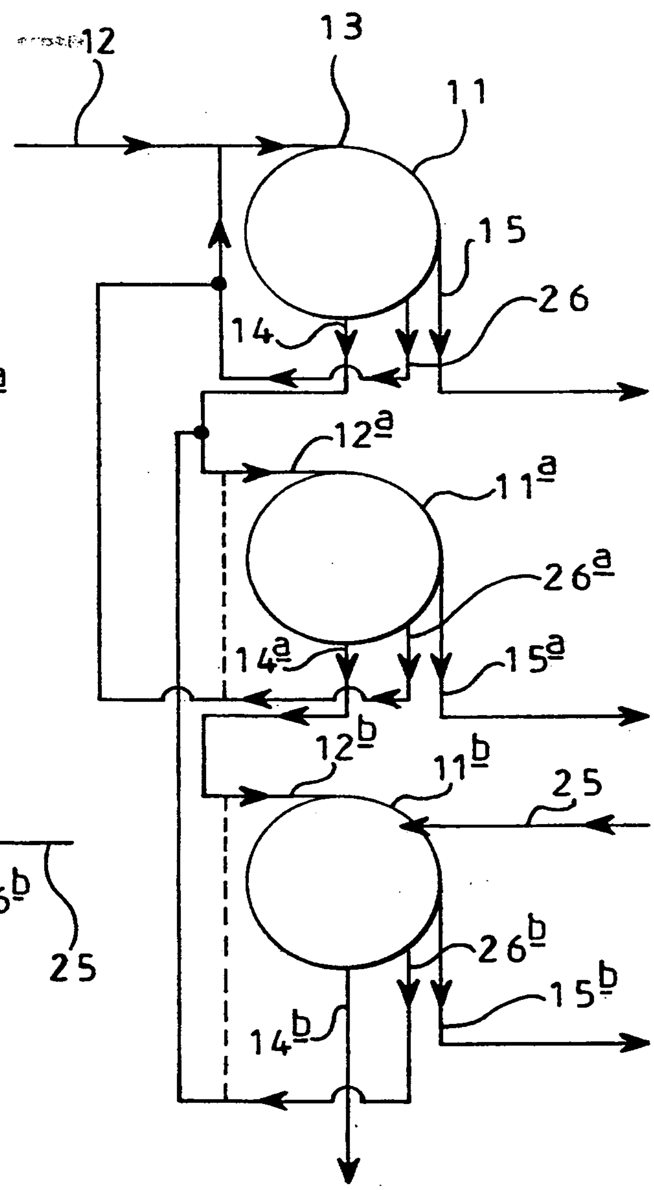
12
13
11
15
26
14
12a
11a
26a
14a
15a
12b
11b
25
26b
15b
14b

FIG 6

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INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification [6] **:**
E21B 43/34, 43/40, B01D 17/02, 17/04, 19/00

A3

(11) International Publication Number: **WO 98/54441**

(43) International Publication Date: 3 December 1998 (03.12.98)

(21) International Application Number: PCT/GB98/01556

(22) International Filing Date: 28 May 1998 (28.05.98)

(30) Priority Data:
9711130.6 29 May 1997 (29.05.97) GB

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(74) Agents: CARPENTER, David et al.; Marks & Clerk, Alpha Tower, Suffolk Street Queensway, Birmingham B1 1TT (GB).

(81) Designated States: AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CU, CZ, DE, DK, EE, ES, FI, GB, GE, GH, GM, GW, HU, ID, IL, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, UA, UG, US, UZ, VN, YU, ZW, ARIPO patent (GH, GM, KE, LS, MW, SD, SZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, ML, MR, NE, SN, TD, TG).

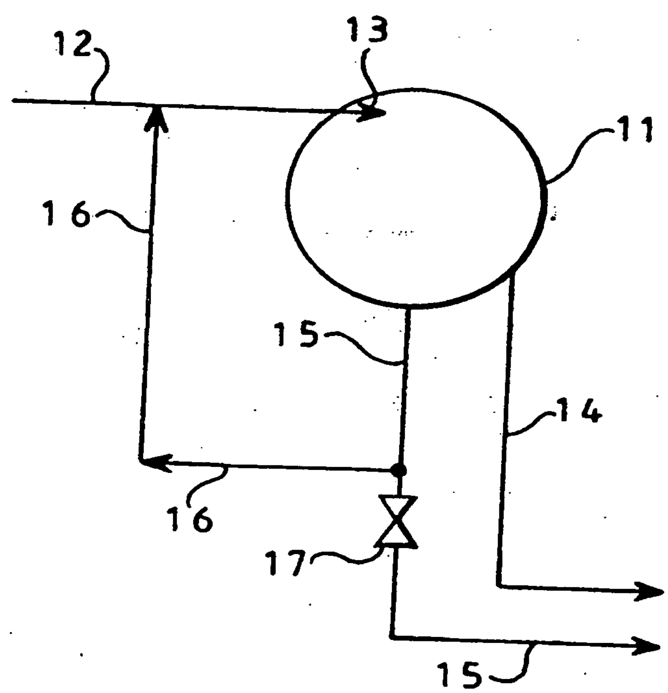
Published
With international search report.

(88) Date of publication of the international search report: 18 March 1999 (18.03.99)

(54) Title: METHOD AND APPARATUS FOR MULTI–PHASE SEPARATION

(57) Abstract

A process and apparatus for separating fluids of different density, primarily gas, oil and water from an oil well production flow (12), including a rotary separation turbine (11) separating at least the gas phase, but preferably also the liquid phases, and preferably returning water (16) to the separation step to increase the water cut of the mixture being separated.



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INTERNATIONAL SEARCH REPORT

International Application No
PCT/GB 98/01556

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 E21B43/34 E21B43/40 B01D17/02 B01D17/04 B01D19/00

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 E21B F01K B01D

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 96 41078 A (BIPHASE ENERGY COMPANY) 19 December 1996 see page 9, line 5 - line 14 see page 9, line 20 - line 28 ---	1,2,9, 17,20, 22,23
A	US 4 478 712 A (ARNAUDEAU) 23 October 1984 see column 7, line 46 - line 52 ---	1,2,17, 20
A	US 4 087 261 A (HAYS) 2 May 1978 cited in the application see the whole document ---	1,2,17, 20
A	US 5 525 034 A (HAYS) 11 June 1996 cited in the application see abstract --- -/--	1,2,17, 20

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
3 September 1998	16. 12. 1998

Name and mailing address of the ISA	Authorized officer
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INTERNATIONAL SEARCH REPORT

International Application No
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C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 5 117 908 A (HOFMANN) 2 June 1992 see abstract -----	1,2,17, 20

INTERNATIONAL SEARCH REPORT

International application No.
PCT/GB 98/01556

Box I Observations where certain claims were found unsearchable (Continuation of item 1 of first sheet)

This International Search Report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
   because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
   because they relate to parts of the International Application that do not comply with the prescribed requirements to such an extent that no meaningful International Search can be carried out, specifically:

3. ☐ Claims Nos.:
   because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box II Observations where unity of invention is lacking (Continuation of item 2 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

see additional sheet

1. ☐ As all required additional search fees were timely paid by the applicant, this International Search Report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.

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   1-12,17,20-24

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest.

☐ No protest accompanied the payment of additional search fees.

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

1. Claims: 1-12,17,20-24

Process and apparatus for separating gas, water and oil with a rotary turbine, including supplying water to increase the water proportion in the process

2. Claims: 13-16,25

Process and apparatus for separation of gas and liquid, using a rotary turbine to remove gas, further subjecting some of the separated products to a second stage separation operating at a lower pressure, or further using a hydrocyclone.

3. Claims: 18-19

Process for separating phases of a multi-phase flow with a rotary turbine, using the rotation of the rotor to generate sufficient pressure for recycling a phase, further using an external energy source.

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/GB 98/01556

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 9641078 A	19-12-1996	US 5664420 A	09-09-1997
		AU 7629396 A	30-12-1996
		CA 2220147 A	19-12-1996
		EP 0839278 A	06-05-1998
		US 5720799 A	24-02-1998
US 4478712 A	23-10-1984	FR 2513534 A	01-04-1983
		AT 380798 B	10-07-1986
		AT 361082 A	15-12-1985
		GB 2106424 A,B	13-04-1983
		JP 58067305 A	21-04-1983
		NL 8203745 A	18-04-1983
		US 4533474 A	06-08-1985
US 4087261 A	02-05-1978	NONE	
US 5525034 A	11-06-1996	US 5385446 A	31-01-1995
		WO 9623129 A	01-08-1996
		US 5664420 A	09-09-1997
		US 5720799 A	24-02-1996
		AU 698268 B	29-10-1998
		AU 1868295 A	14-08-1996
		EP 0805909 A	12-11-1995
US 5117908 A	02-06-1992	DE 3810951 A	12-10-1989
		IN 172462 A	14-08-1993
		CN 1037376 A,B	22-11-1989
		WO 8909323 A	05-10-1989
		EP 0407408 A	16-01-1993
		JP 3503555 T	08-08-1989